Feed Flow Studies of Waste Coprocessing Feed Slurries

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Introduction

Advanced methods of recycling waste materials are being developed[1]. These methods attempt to use existing technologies, such as direct liquefaction, to convert waste materials into higher value fuels and chemicals. These technologies require a feed system capable of handling a diverse suite of feed materials. Most likely, the resulting slurry would be a heterogeneous mixture of components differing in state, viscosity and density. This heterogeneity creates a difficult problem with respeet to potential feed systems. Recently, a feed flow loop unit was designed and constructed at FETC capable of studying the flow properties of these mixtures.. This paper discusses the feed flow loop design and some of the initial results that have been obtained with the unit.

Experimental

A feed flow loop was designed and constructed to investigate the flow properties of slurries containing heterogeneous mixtures of coal, oil, waste plastics, rubber, or biomass. The loop essentially allows for controlled straight flow through a channel. The pressure drop across the channel is measured using a differential pressure transducer. The pressure drop, flowrate, cross-sectional area of the pipe, and pipe length can then be used to calculate the effective viscosity.

The flow loop was designed to measure the effective viscosities of coprocessing slurries. A simplified schematic of the loop is detailed in Figure 1. The lines following the pump are 0.0127 m (0.5") ss tubing, 0.00089 m (0.035") wall. The loop has two straight sections each 5.03 m in length. A pressure transmitter, with a remote seal and range of 0-5.17×10^6 Pa, is near the end of the return straight length. A differential pressure transmitter, with remote seals and pressure differential range of 0-6.89×10^5 Pa, is also on the return length with the remote seals 3.05 m apart. A thermocouple is located in the middle of the 3.05 m section where the pressure drop is measured. All instrumentation readings are monitored and recorded on a computer.

The loop is designed to be used with slurries and mixtures having effective viscosities in the range of 100 - 10,000 cP at temperatures up to 200°C and flow rates of 0.38 - 3.8 l/min. This allows for testing of mixtures at shear stresses and shear rates ranging from 10 - 500 Pa and 50 - 500 s^{-1}, respectively.

In the operation of the flow loop, the feed slurries are prepared and heated to the desired temperature in the mix tank. The slurry is then circulated in a short loop until it is well-mixed. Once the slurry is well-mixed and the desired temperature reached, the slurry is routed through the flow loop. Samples are collected in the product receiver at specific time intervals and used to provide mass flow rates and densities. Samples and measurements are taken at different flow rates and temperatures and the conditions are repeated to insure that the slurry rheology is not time dependent.

Effective Viscosity Calculation

The general viscosity equation for laminar, fully developed, incompressible, and steady flow in a pipe is:

$$\mu_e = \tau_w / (8 * v/d)$$

where: τ_w = shear stress at the wall = $d * \Delta P / (4 * L)$
v = average velocity (m/s)
d = diameter (m)
L = length (m)
ΔP = pressure drop (Pa)

$\mu_e = d*\Delta P/(4*L)/(8*v/d) = d*\Delta P/(4*L)*(d/8*v) = d^2*\Delta P/(32*L*v)$

$\boldsymbol{\mu_e = d^2*\Delta P/(32*L*v)}$

The Reynolds Number (N_{Re}) for flow in a pipe is:

$\boldsymbol{N_{Re} = \rho*d*v/(\mu_e)}$

where: ρ = density (kg/m^3)

For the fluids reported in this paper the N_{Re} is in the range of 3-24, in the laminar flow region.

The entrance length (L_E) for fully developed flow is defined by Langhaar[2] as:

$\boldsymbol{L_E = 0.0575*d*N_{Re}}$

For the fluids reported in this paper the L_E is in the range of 0.002 - 0.03 m. The distance of the pressure transmitter from the bend is 1.14 m (greater than L_E).

A plot of the effective viscosity versus shear rate, 8*v/d (s^{-1}), can be used to determine Newtonian or Non-Newtonian behavior.

Results:

Several feed mixtures containing coal, plastics, and heavy oil have been tested in continuous operations at FETC. The conversions and yields observed during these tests have been reported[3]. A typical composition was: 70 wt% heavy oil, 15 wt% coal, 7.5 wt% high density polyethylene, 5.5 wt% polystyrene and 2 wt% polyethylene terephthalate (or polypropylene), essentially a 70:15:15 mixture of oil:coal:plastics. At the feed conditions for the test (temperatures of 50-200°C), the feed slurry contained a solid component (coal) and a viscosity that ranged from 250 to 2000 cP measured by a Brookfield Rotating Spindle Model MV8000 Viscometer.

The importance of controlling viscosity of the feed mixture was evident early in the waste coprocessing effort. For example, a typical feed, consisting of a 70:15:15 mixture was investigated using the Brookfield Viscometer prior to construction of the flow loop. At temperatures of 150°C, the viscosity of such a slurry was approximately 1800 cP. High pressure drop was observed in the feed lines of the continuous unit at this temperature, resulting in operating difficulties that eventually caused the unit to be shut down. At the same temperature, a different feed mixture (70:22.5:7.5) possessed a viscosity of 250 cP. Under these conditions, the coal solids were not adequately suspended in the slurry and settled out, causing plugging in the lines of the continuous unit.

Smoothest operation of the continuous unit occurred when feed viscosities were maintained in the range of 800 to 1000 cP. For a feed mixture of 70:15:15, the viscosity was 1000 cP at 180°C; for a feed mixture of 70:22.5:7.5, the viscosity was 800 cP at 110°C. (Further details of the feed viscosities and flow properties have been reported elsewhere[4].) Therefore, during continuous operations, the optimum conditions for feeding varied widely with feed composition.

The feed flow loop was designed and constructed to test the flow properties of feed slurries. This will enable a more detailed evaluation of the flow properties and the requirements to effectively feed these slurries. This will eliminate the necessity of operating the continuous unit to evaluate the ease of operation. Essentially, the feed flow loop will permit "on-line" measurement and prediction of the rheological and flow properties of prepared feed slurries prior to continuous testing. To date, the feed flow loop has been shaken down and tested with an FCC decant oil. The unit was operated at two temperatures; 50°C and 60°C. A plot of the effective viscosity versus shear rate for the two temperatures is shown in Figure 2. Also included in Figure 2 are separate viscosity measurements for the materials at the same temperature using the Brookfield viscometer. Deviation from a horizontal line would indicate that the fluid is behaving in a non-Newtonian manner. The slope of the lines at the two temperatures indicates a slight shear-thinning behavior for the decant oil over the shear rate tested. Also, it is encouraging that the calculated effective viscosities from the flow loop are similar to the viscosities measured by the Brookfield Viscometer.

Summary

Waste/Coal feed mixtures can be successfully fed and converted in units designed for hydrogenation and coal liquefaction. An envelope of 250-1800 cP exists outside of which continuous operations can not be maintained. The optimal envelope for feeding these slurries appeared to be in the range of 800-1000 cP. The design and construction of the feed flow loop described here will permit more detailed evaluations of the flow properties of heterogeneous mixtures. The flow loop was successfully tested using decant oil.

Disclaimer

Reference in this paper to any specific commercial product or service is to facilitate understanding and does not imply its endorsement or favoring by the United States Department of Energy.

References

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Figure 1. Simplified Flow Diagram of the Flow Loop

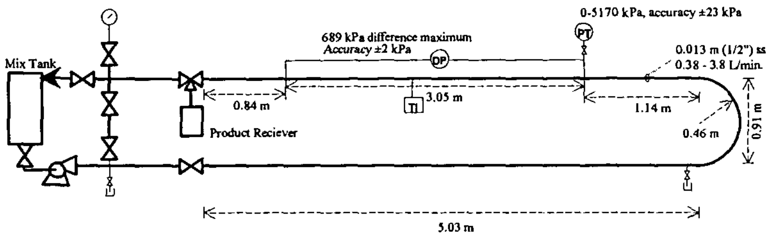

Figure 2. FCC Decant Oil Flow Curve